First Draft Optical Design

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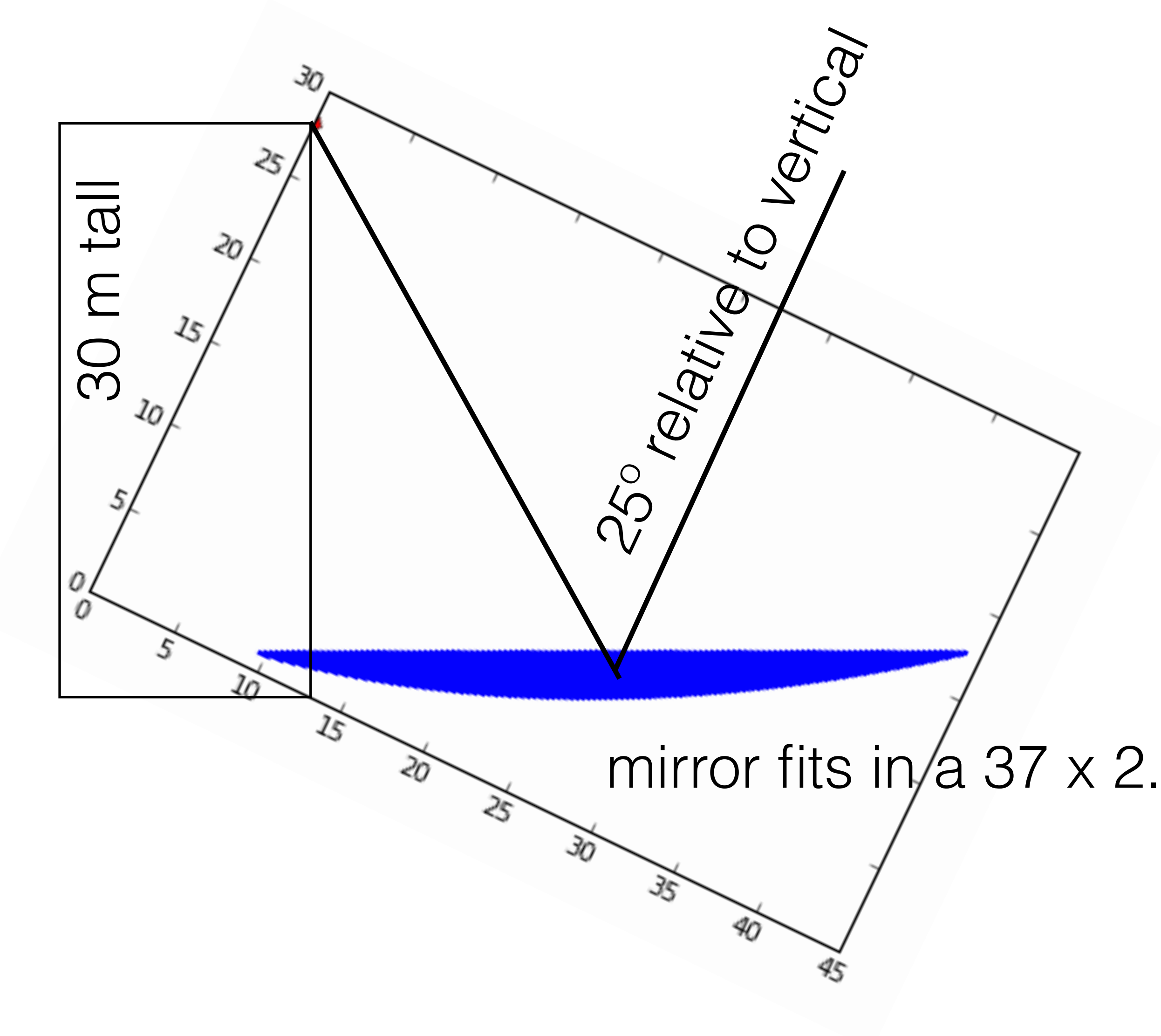
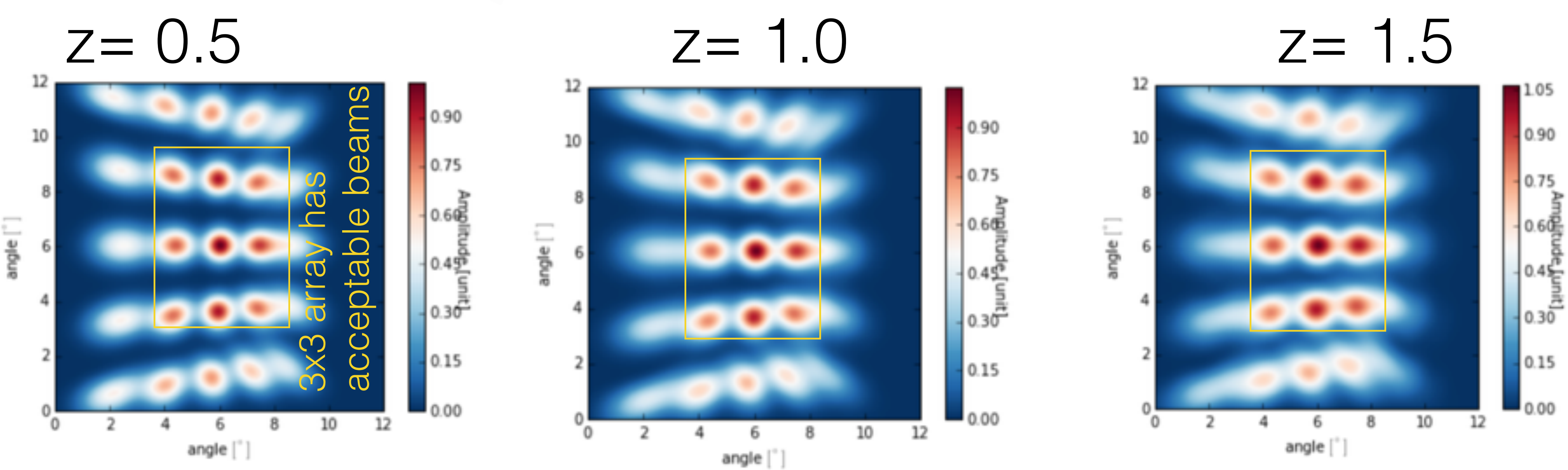
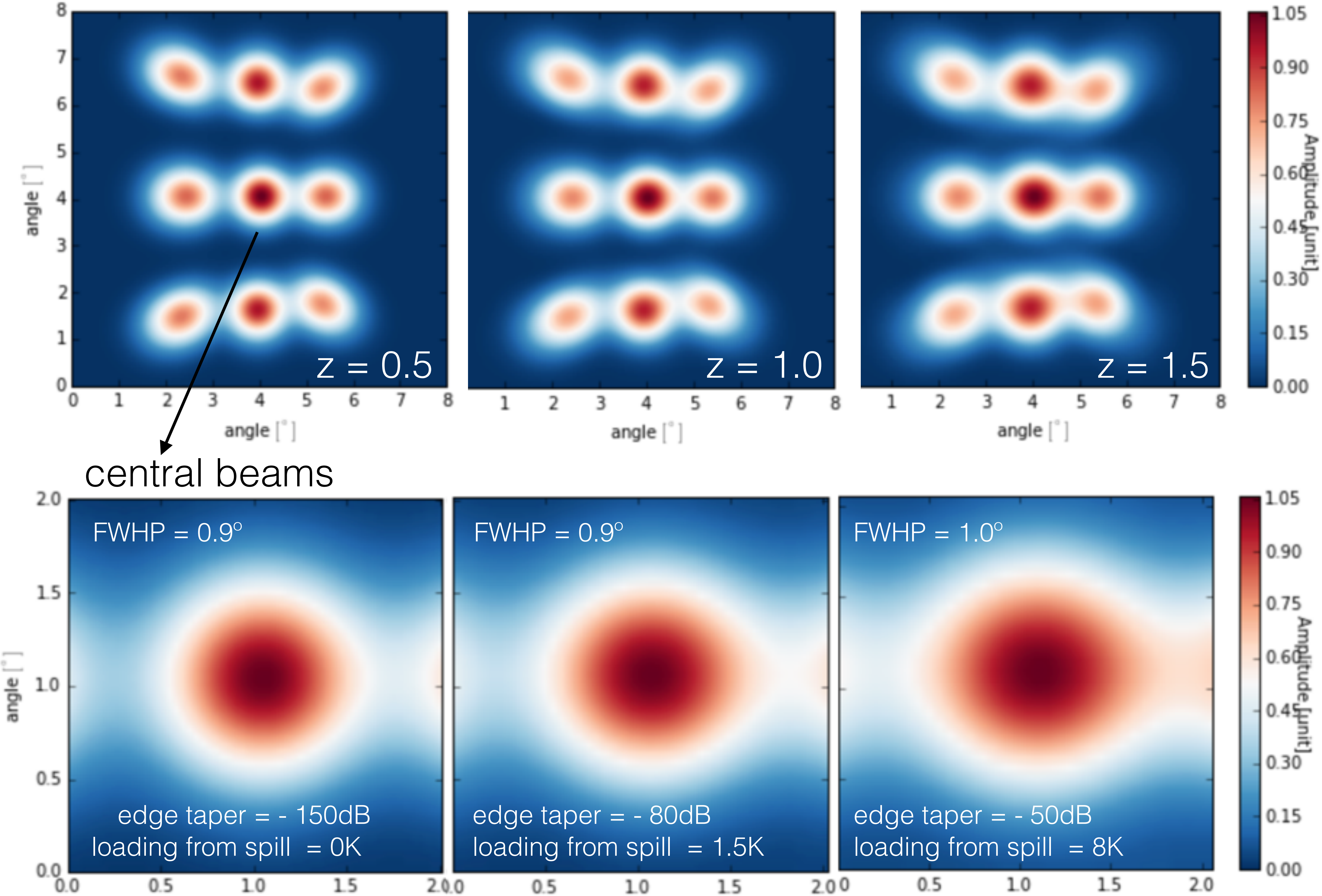


D = 35 m
F# = 0.8
X_cent = D/
FWHP feed = 14° @ 42 cm
feed tilted toward the dish center

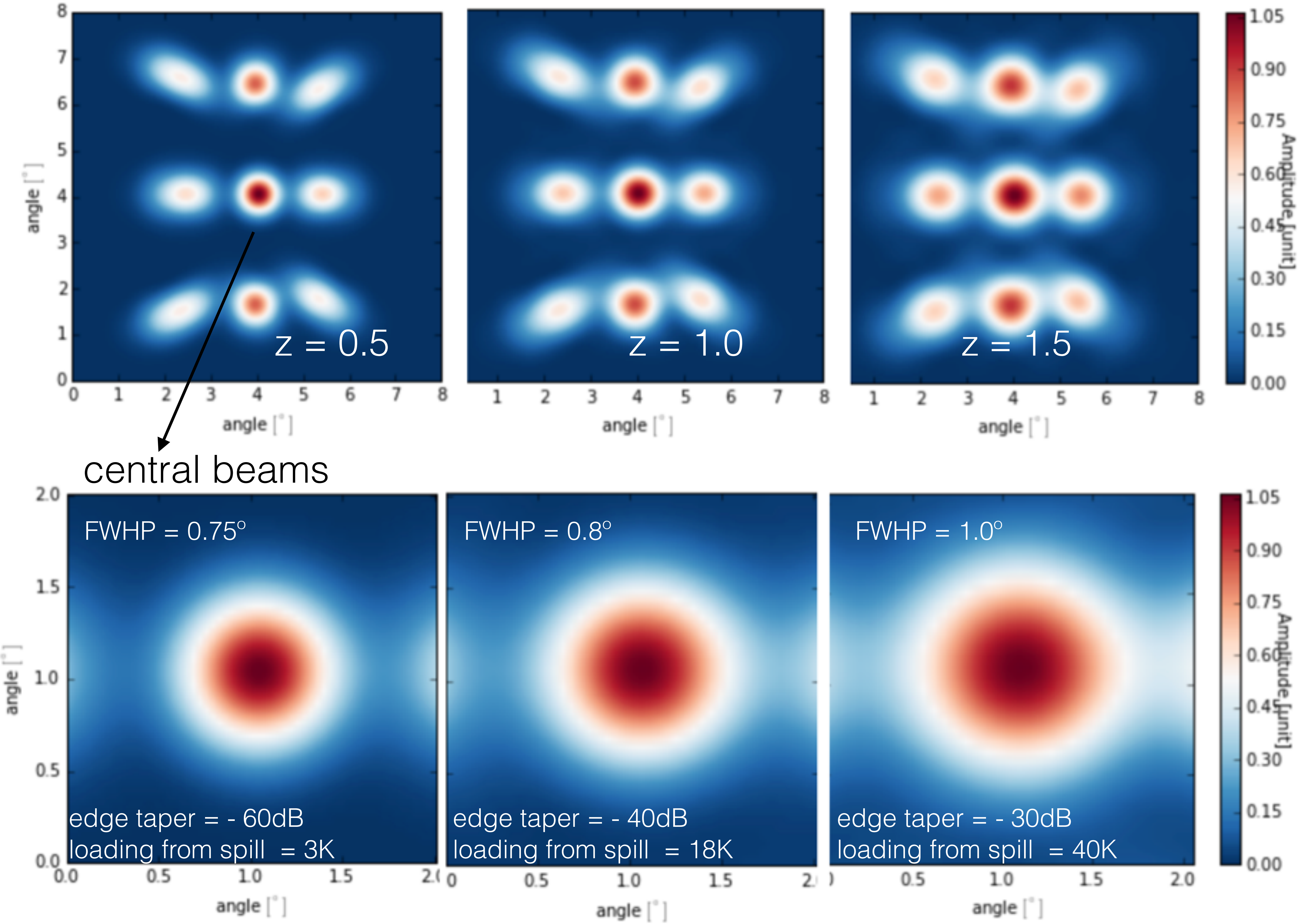


Simulations with a realistic Feed “under illumination”



- the feed was chosen to under illuminate the reflector at all frequencies
- thus the beam size is determined by the illumination
- this results in low spillage and a frequency independent beam
- the frequency independent beam could be advantageous for point source foregrounds
- 50 m gives 0.6° FWHP with this design—- seems to be 2x worse than 0.1°, so probably OK

Simulations with a realistic Feed “agressive” illumination



- the feed was chosen to not under illuminate the dish
- thus the beam size is determined by the dish
- this results in smaller beams, but at the cost of lots of noise especially at high redshift

Optics Questions:

- **What is the scientific trade for under-illumination vs aggressive illumination of the telescope?**
  - advantages for under-illumination
    - lower noise
    - frequency indépendant beam
  - advantages for agressive illumination
    - smaller beam size

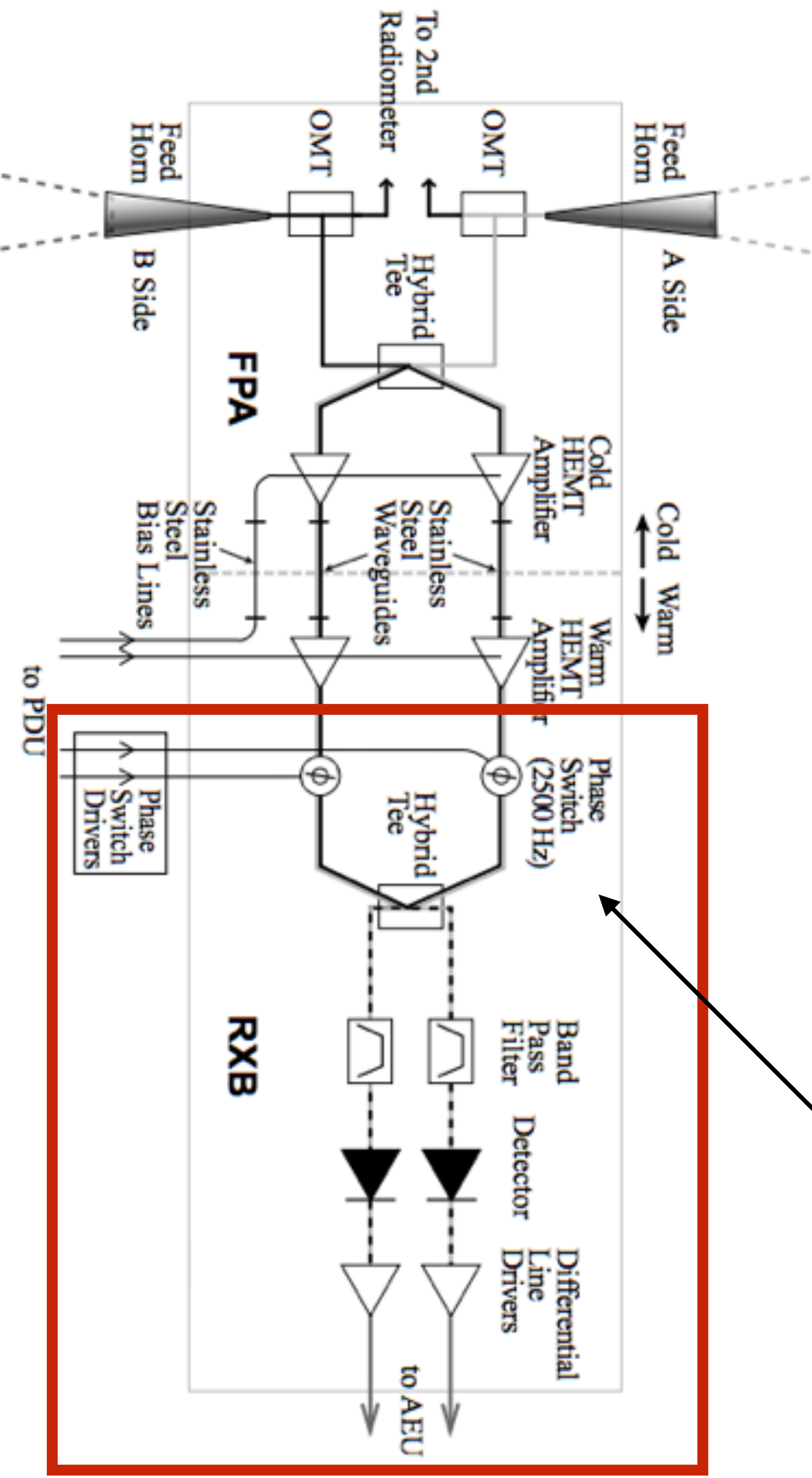
Receiver Ideas

Concept

- Copy the design from CBASS (or WMAP) see below
- front end based on commercially available Low Noise Amplifiers, and hybrid tees (simple to buy)
- FPGA backend implemented on a ROACH2 board
    - requirements below after discussing the CBASS and WMAP designs

WMAP Style

http://arxiv.org/pdf/astro-ph/0301164v2.pdf

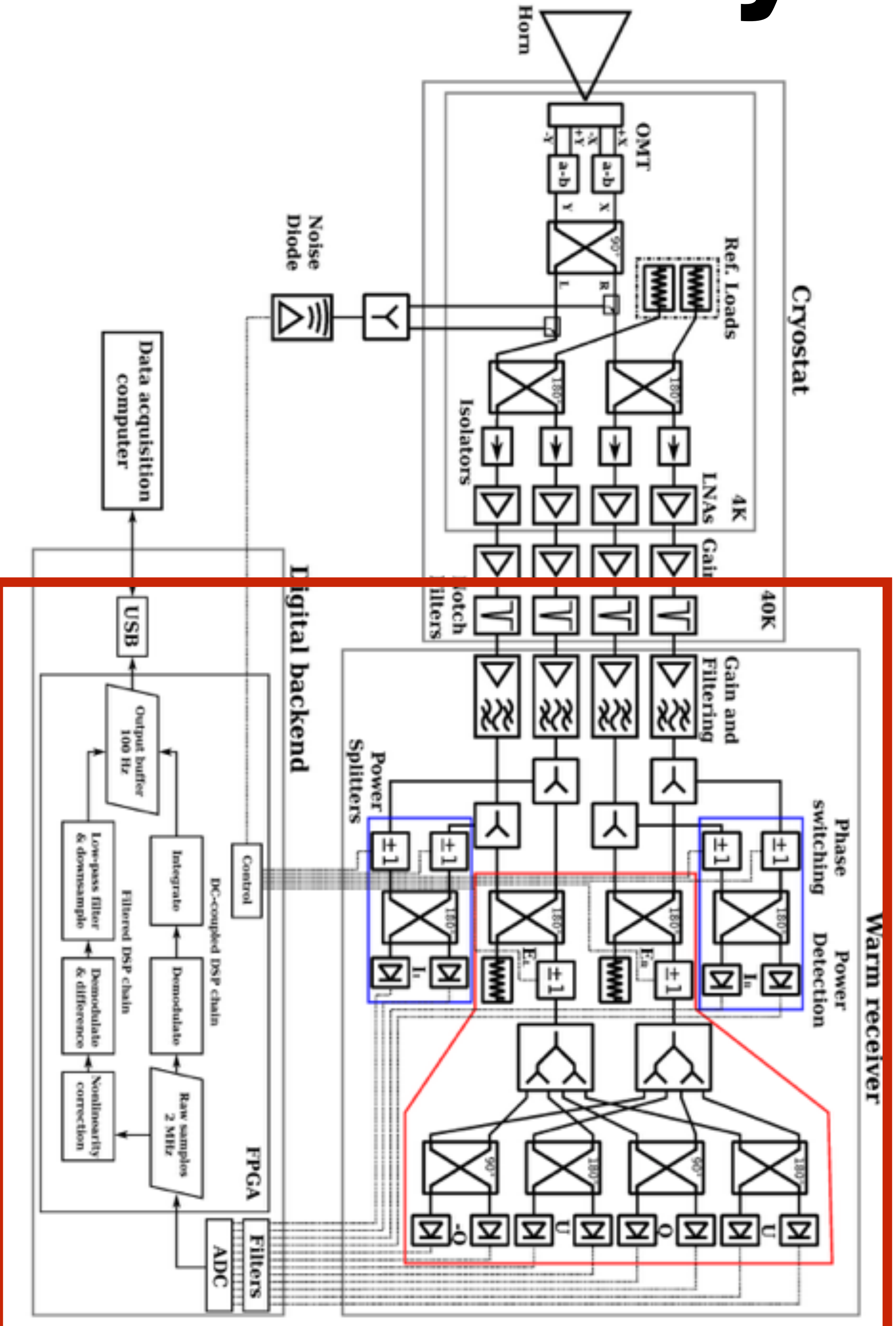


- pseudo-correlation receiver
- sensitivity sqrt(2) Tsys / sqrt(BW) on each difference (need to double check)
- advantages:
  - differences two horns removing any common signals (RFI or atmospheric drifts)
  - works at any temperature
- disadvantages:
  - removes scales larger than the horn separation
  - differences only between polarization pairs, and some RFI may have a non-trivial polarization dependance
- implementation ideas:
  - replace everything in the box with digital signal processing on a ROACH-2

CBASS Style

http://arxiv.org/pdf/1310.7129v2.pdf

http://www.aanda.org/articles/aa/pdf/2002/33/aah3535.pdf



- also a pseudo-correlation receiver
- sensitivity: as with WMAP, sqrt(2) Tsys / sqrt(BW) on each difference, (assuming the reference loads are close to the sky temperature)
- advantages:
  - sensitive to large scales, limited by atmosphere and scan strategy, but not differencing
  - also a polarimeter potentially helpful for source removal, adds ancillary science, and helpful for RFI characterization
  - for an array, we could identify linear combinations of output that are contaminated and subtract them off to reduce RFI, this would give more freedom than the WMAP approach
- disadvantages:
  - requires ~4K cryogenics.   This boosts the cost of a cryocooler from ~10K to about 20K. For 100 receivers, this would amount to
  - if you form the difference between two horns (to recover the same measurement as in WMAP) then you get sqrt(2) worse noise. However, for a large array you get lots of measurements so this may be overly pessimistic— I need to think about it.
- implementation ideas:
  - replace everything in the box with digital signal processing on a ROACH-2 (this is a trivial difference (eg a few extra phase switches and extra correlation pairs) from the WMAP version suggested on the previous slide)

Overall Thoughts

- The front end and back end are nearly identical for both approaches

- develop and test the ROACH-2 based back end as a first step

- design a front end and back end that works for both designs

Requirements / Implementation thoughts

- to implement the CBASS receiver, we need to digitize **4 channels** coming onto the ROACH. This can be done by instilling two iADC cards each with two channels.
- **bandwidth: ultimate goal: 350 MHz - 1000 MHz** (eg z = 0.5 to z = 3) (Less is fine **for now, say 600 MHz to 1000 MHz)**
  - Casper has ADC boards that are compatible with this goal including the
    - ADC1x5000-8 (https://casper.berkeley.edu/wiki/ADC1x5000-8) 2 channels, 2.5 Gs/S = 1.25 GHz max frequency.
    - ADC2x1000-8 (https://casper.berkeley.edu/wiki/ADC2x1000-8) 2 channels, 1 GS/s = 500 MHz max frequency which means we could cover ~ 600 - 1000 MHz if we analogue mix down by 2 before going onto the board.
- Other requirement: Add a spectrometer to the output of the receivers described in CBASS or WMAP. 1 MHz is a great start, but higher resolution could be fantastic.
- Given what already exists, this appears doable, but will likely be much work.

High Level Thoughts

Do we want a cryogenic receiver?
What tests do we do?

Noise Estimates

	Sky Noise	spillage (under illuminated)	front end (horn + OMT + hybrid)	amplifier	best noise temperature guess	sensitivity per 1 MHz wide channel	improvement factor over room T (60K)
Z = 0.5	4 K	0 K	5K	4.5 K	15 K	21 mKrt(s)	**16**
Z = 1.0	5 K	1.5 K	5K	4.5 K	16 K	23 mKrt(s)	**14**
Z = 1.5	6.5 K	8 K	5K	4.5 K	24 K	34 mKrt(s)	**6**
source for estimates	see next slide for figure	optics design (previous slide)	guess	http://radiometer.caltech.edu/datasheets/amplifiers/CITLF2.pdf			

Sky Noise

	Sky Noise
Z = 0.5 (930 MHz)	4 K
Z = 1.0 (700 MHz)	5 K
Z = 1.5 (560 MHz)	6.5 K

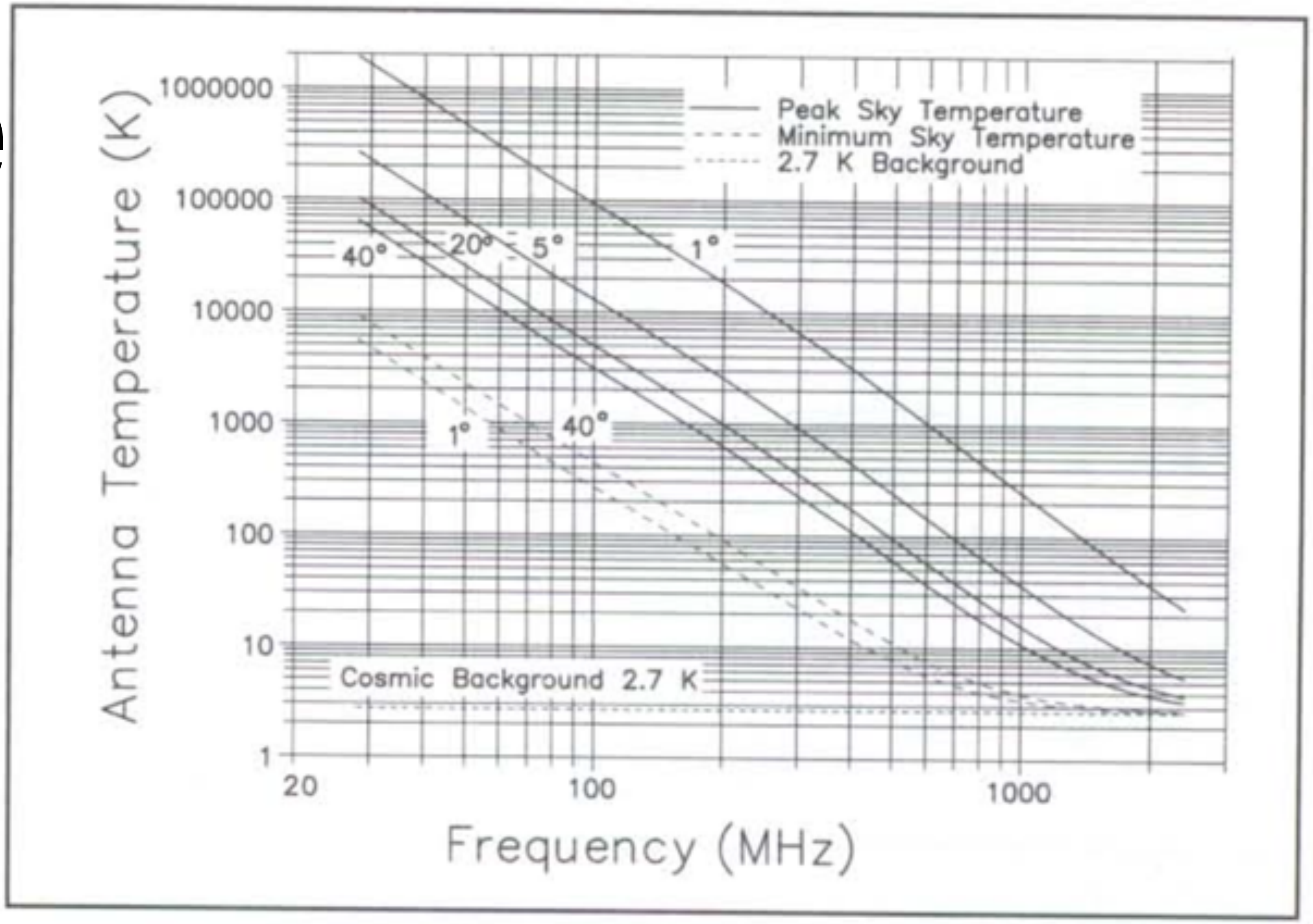


Figure 6—The maximum and minimum sky temperatures for antenna beamwidths of 1°, 5°, 20° and 40°, at frequencies from 28 MHz to 2.4 GHz. Note the logarithmic axes; the peak temperature ranges from about 1,000,000 K at ~30 MHz to only a few kelvins at 2 GHz. Except for the 1° beamwidth, the brightest emission is always the galactic center. Even with the relatively broad 40° beamwidth, there is still a ratio of 6:1 or 7:1 between the maximum and minimum antenna temperatures over most of this frequency range. At about 1 GHz and above, the 2.7 K cosmic background radiation dominates the lowest sky temperature. This plot does not include additional noise from terrestrial sources: atmosphere, ionosphere or ground.

Thoughts on Tests

1. get the ROACH-2 back end working, test on the sky to get RFI

2. get the front end of the receiver together, test RFI at BNL— if good proceed to make dish there

3. if the RFI is bad at BNL, make the dish elsewhere

4. start out with a warm front end, develop the cold front end second, choose to use the same bias electronics and amplifiers to simplify the upgrade.

Note on slew speed requirement

- Given that we have lots of spectral bands, and the atmospheric emission should have a smooth frequency dependance, I don’t think we need to scan fast to eliminate the atmosphere.   This will lead to a huge cost savings in the mount.